Department of Agriculture and Fisheries for Scotland

Experiments on the Cultivation of Oysters in Scotland

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CORRIGENDUM

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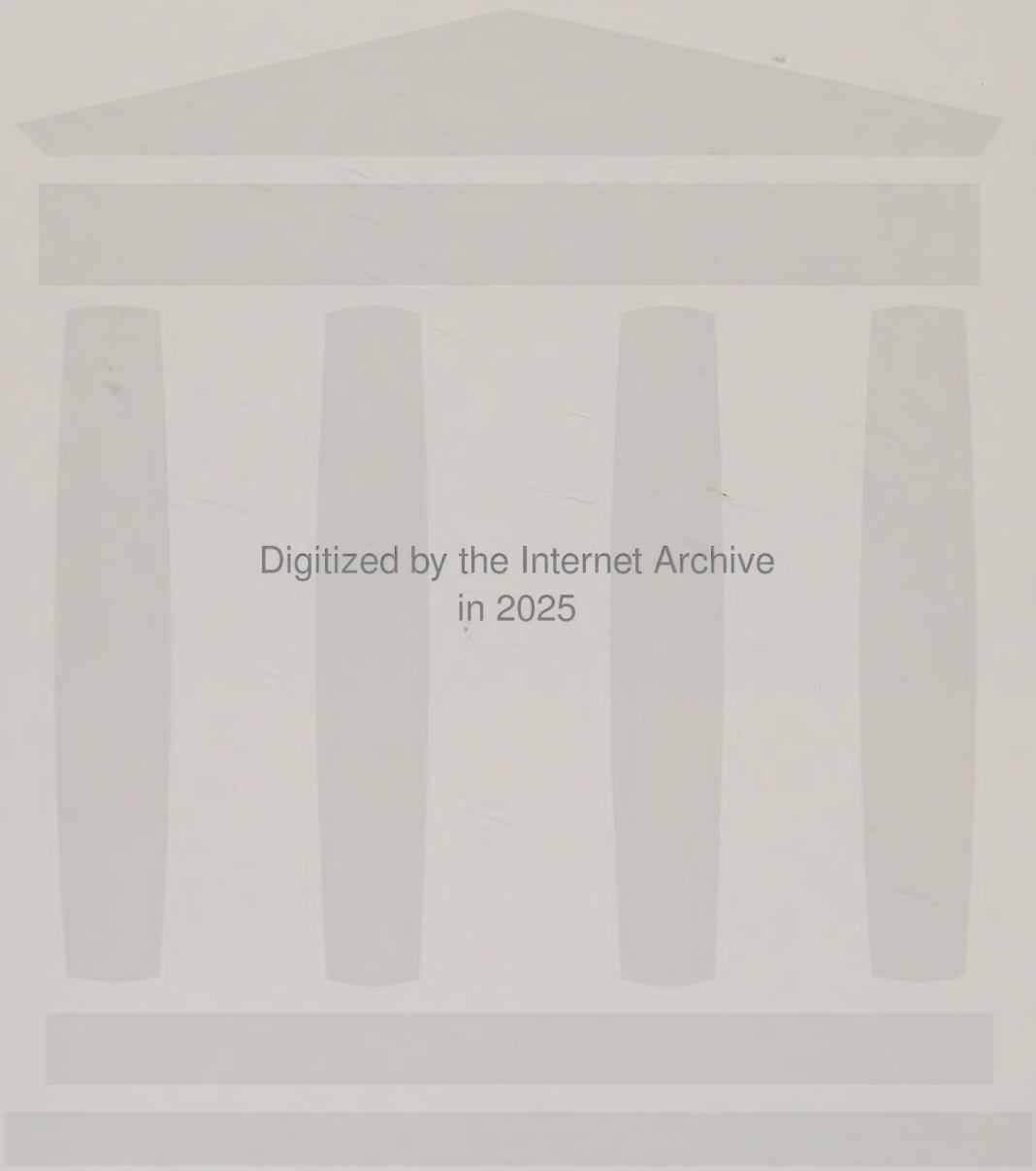
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Experiments on the Cultivation of Oysters in Scotland

J Drinkwater and T R W Howell

Marine Laboratory Aberdeen

Introduction

The European flat oyster, *Ostrea edulis* L. was once abundant in many parts of Scotland and supported an important commercial fishery. During the early years of this century there was a rapid decline, and there is at present only one fishery for this species (in Loch Ryan). Attempts were made to revive the fishery in other places (see Millar, 1961) but were not successful.

The availability of hatchery produced spat of both the native oyster (*O. edulis*) and the Pacific oyster (*Crassostrea gigas* (Thunberg)) opened up the possibility of cultivating both these species in Scottish waters. The aims of the experiments described in the present paper were to compare the survival and growth rates of *O. edulis* and *C. gigas*, to evaluate a number of fairly typical areas and to investigate various methods of raft and shore cultivation.

Work on mussels (Mason and Drinkwater, 1981) gave an indication of some places worthy of further study. Linne Mhuirich (an arm of Loch Sween, Argyll), was chosen as an area likely to yield good growth and fattening of oysters. A group of lochs in north west Scotland were also selected to provide a variety of conditions. This group included Loch Ardvar and Loch Nedd in Sutherland and Loch Thurnaig and Loch Torridon in Ross-shire. To reduce the amount of travelling involved the later work was limited to the Sutherland lochs.

Materials and Methods

Batches of seed oysters were obtained from the Scottish Sea Farms Ltd hatchery on Loch Creran, Argyll. In the initial experiments in 1973 two kinds of cages were used. The first consisted of a wooden frame with the top and bottom covered with plastic mesh (diagonal of mesh 7mm). The second type were made of a tube of similar mesh with the ends sewn up in directions at right angles to each other so that the cage was kept open in a roughly tetrahedral shape similar to a well-known confection called a "humbug". Neither cage was found satisfactory, and they were replaced later by a tray 60 x 40 x 10cm in size made from plastic coated wire mesh. A lipped lid was held on with hooked lengths of elastic cord. The mesh diagonal was 14mm and finer mesh linings were used when required. The trays were stacked on the shore or hung from rafts similar to those used for mussel experiments (Mason and Drinkwater, 1981) consisting of a steel frame supported by drums filled with expanded polystyrene, or of a new type in which the frame was supported by four large inflatable buoys.

The contents of the trays were examined at intervals of two to three months, the oysters counted, weighed and replaced in the trays after the meshes had been thoroughly scrubbed to remove fouling organisms. It was not possible to obtain individual weights in the field, but samples were returned to the laboratory for weighing and for determining wet and dry weights of meat and shell.

Temperatures at a series of depths were taken at each place on each visit. Later maximum and minimum thermometers were placed amongst oysters in trays at Ardvar and the results recorded during visits. Salinities were also determined, at first from density measurements but later using a direct reading refractometer. Tidal heights at Ardvar were fixed using temporary tide poles and noting the heights of important structures in relation to the incoming tide.

Comparison of Sites

The areas studied are shown in Figure 1. Linne Mhuirich is a shallow sheltered inlet separated from Loch Sween by a narrow entrance with a shallow sill. The tidal range is less than 1m, and there is little freshwater inflow. Loch Ardvar is very sheltered and also has a shallow sill, but the tidal range is more than 4m at spring tides. There is some fresh water inflow but apart from a very shallow surface layer salinities remain high. Loch Nedd, though sheltered, is rather more open to the Minch, and has a considerable fresh water inflow causing lowered surface salinities at times. Loch Thurnaig is a sheltered inlet of Loch Ewe with no wide variations in salinity. The Loch Torridon site was in the upper basin, which has considerable fresh water inflow and at times salinities are low to a considerable depth.

Further information on these areas is given by Millar (1961, Milne (1972) and Mason and Drinkwater (1981).

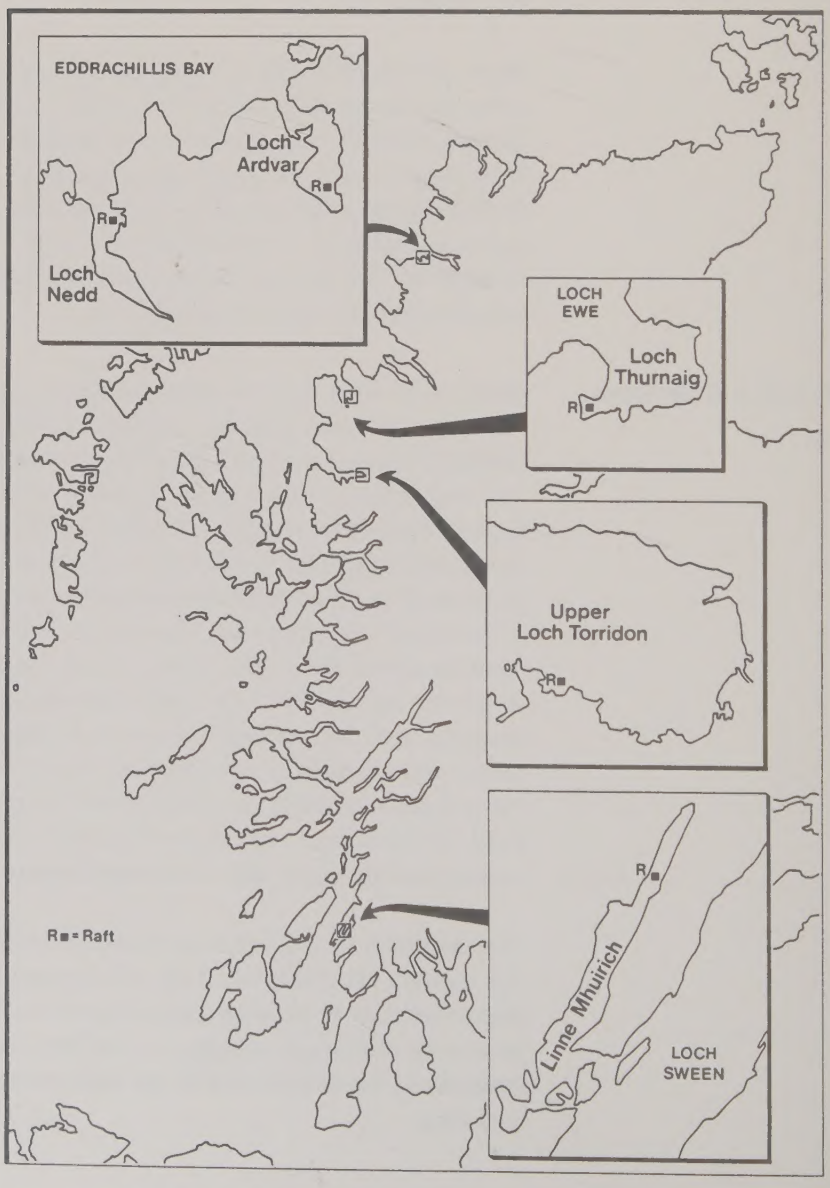

Figure 1. Map showing sites of experiments.

Environmental Conditions

The temperature and salinity were measured at the five sites over a period of 3 years. Measurements were taken at the surface, at ½—1m intervals down to 3m, and at the sea bed. At all sites temperatures varied little between the surface and 3m, normally by less than 1°C, the greatest recorded difference being 2.5°C. During the summer months the surface temperature was invariably higher than at 3m, in the winter the situation was reversed. The temperature difference between the sea bed and 3m was never more than 0.3°C.

The temperatures at 2m, the standard depth of the suspended oyster trays, are shown for the five sites over a three year period in Figure 2. Linne Mhuirich had both the highest and the lowest temperatures, being shallow with a much lower exchange of water than the four more northerly lochs. Significantly low salinities, *ie* below 30‰ (Figure 3), were rarely recorded at 2m and observed in Linne Mhuirich and L. Torridon only during the October and December visits in 1974. During the latter visit to L. Torridon this surface layer of brackish water extended down to 3m. Although surface salinities as low as 15.5‰ occurred at the other sites readings below 30‰ were not seen deeper than 1m.

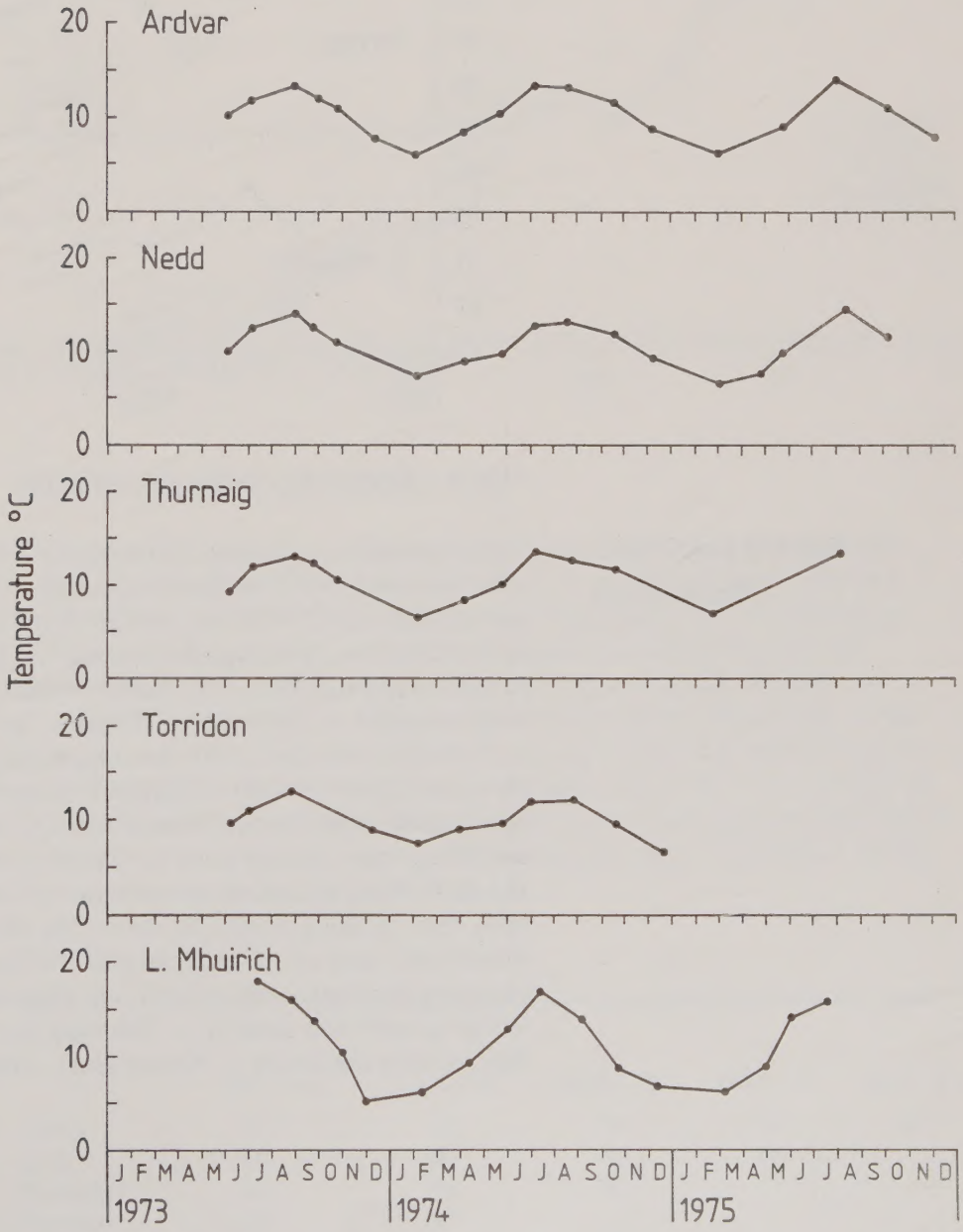

Figure 2. **Temperature at 2m at the five experimental sites.**

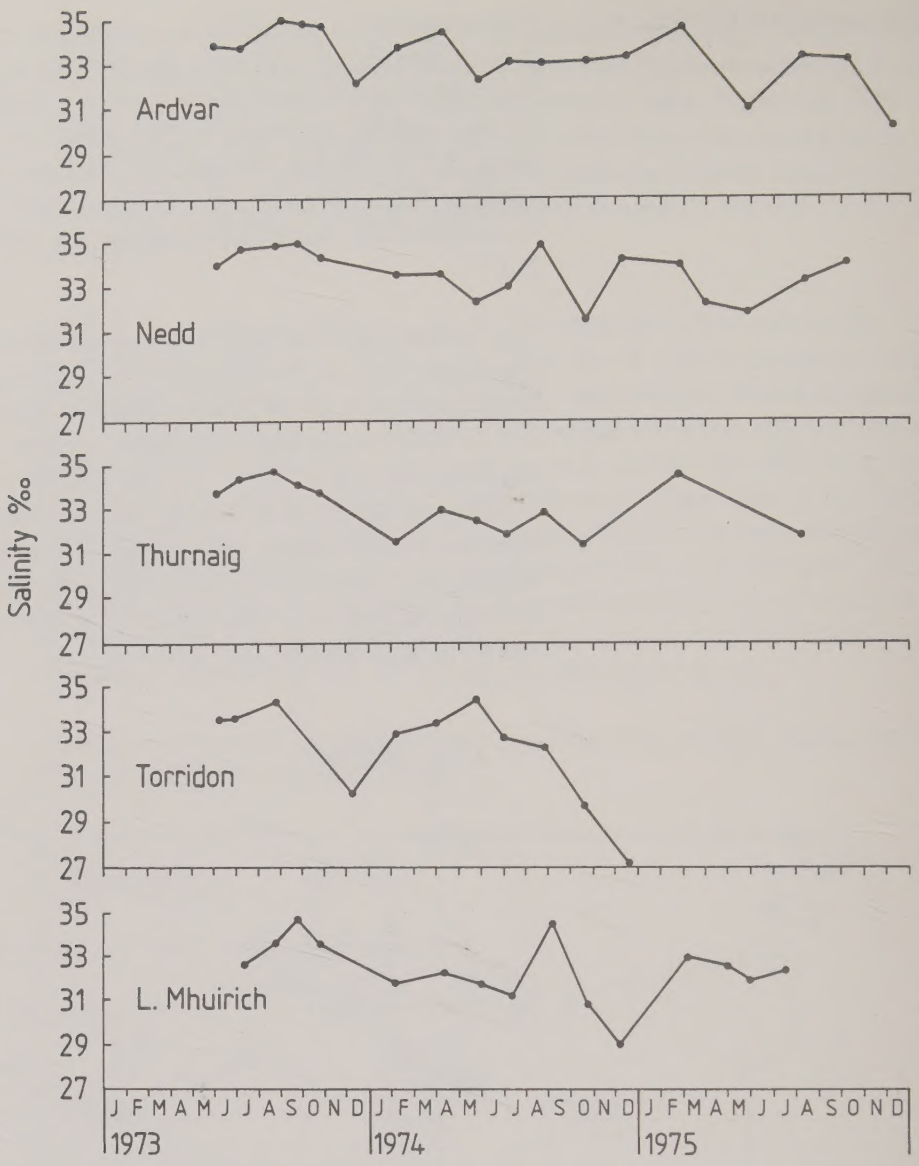

Figure 3. Salinity at 2m at the five experimental sites.

Survival and Growth
Ostrea edulis

Two cages each containing 200 seed of 10mm size and mean weight 0.1g were hung at a depth of 2m in each area in May 1973. Mortality was high and variable in the first few months, but decreased later. It was necessary to combine the contents of trays and re-distribute the animals so that roughly equal numbers were grown in each cage. Best survival rates (Table I) were recorded in Linne Mhuirich and L. Ardvar. The lowest was in L. Torridon. Mortality was very low in the third and subsequent years. Mean weights are shown in Figure 4. Growth was rapid during the summer but stopped in late autumn and there was usually a decrease in mean weight over the winter, possibly due to loss of condition in the meat and abrasion of the shell. The best overall growth was in Linne Mhuirich, but even there it took four growing season to reach 74g (September 1976), when most individuals were of commercial size. In the other places initial growth was slow but the overall growth rate showed a similar pattern. The 1974–75 winter growth was good at L. Thurnaig. Commercial size was reached after five growing seasons at L. Ardvar and L. Nedd.

Table I

Mean annual survival of *O.edulis* (%) 1973 seed (10mm) suspended from rafts at a depth of 2m

	1973–74	1974–75	1975–76	1976–77	1977–78
Ardvar	36	82	99	95	91
Nedd	27	69	95	91	97
Thurnaig	24	84	100		
Torridon	18	56			
L. Mhuirich	51	80			

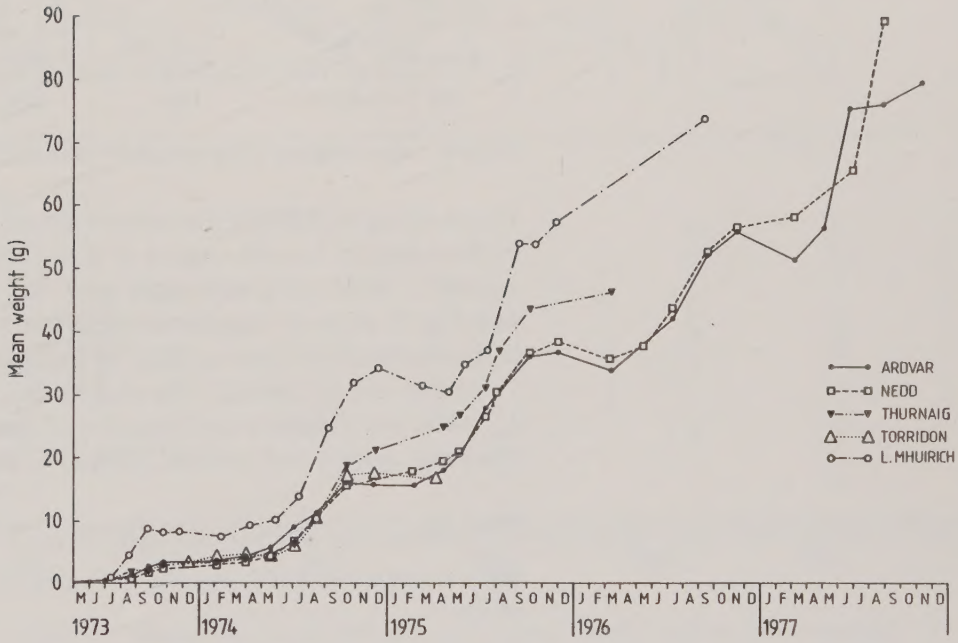

Figure 4. Mean weight of *Ostrea edulis* (1973 seed).

Crassostrea gigas

The results of a similar experiment started in 1973 using 10mm Pacific oyster spat are shown in Table II and Figure 5. Initial mortality was very high, the best survival during the first year being only 19%. In subsequent years survival was good. The pattern of growth was similar to that for *O. edulis,* but the rate of growth was roughly twice as high. Growth of *C. gigas* in Linne Mhuirich again started off much better than in the other areas, but was later overtaken by L. Thurnaig, where the 1974-75 winter growth was again good. During the same winter period the mean weight of the L. Mhuirich animals fell considerably. A commercial size was attained in Linne Mhuirich after only two growing seasons (73g in December 1974). The other areas required a further season.

Table II

Mean annual survival of *C. gigas* (%) 1973 seed (10mm) suspended from rafts at a depth of 2m

	1973–74	1974–75	1975–76	1976–77	1977–78
Ardvar	16	80	81	86	94
Nedd	15	90	95	91	
Thurnaig	11	98	100		
Torridon	13	97			
L. Mhuirich	19	91	71		

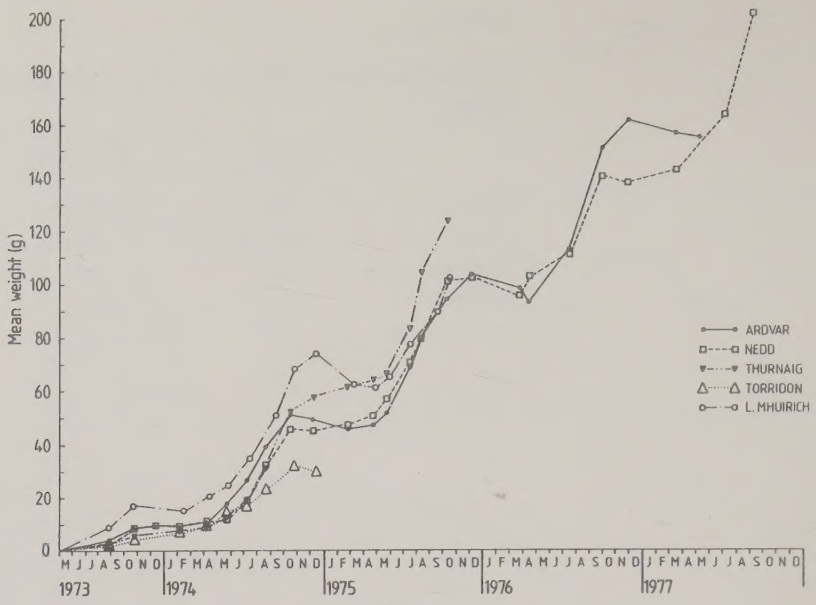

Figure 5. Mean weight of *Crassostrea gigas* (1973 seed).

It was thought possible that some animals had been lost through the meshes of the cages in the early weeks of this experiment so a repeat experiment was started in 1974 using wire cages with fine mesh linings. The results (Table III and Fig. 6) show an improvement in initial survival. Growth was again good in Linne Mhuirich (nearly 100g by October 1975), with L. Thurnaig and L. Ardvar not far behind. The experiment was continued at L. Ardvar and L. Nedd and showed a continuation of the same pattern. By October 1978 the mean weight had reached 228g at L. Ardvar.

Table III

Mean annual survival of *C. gigas* (%) 1974 seed (10mm) suspended from rafts at a depth of 2m

	1974–75	1975–76	1976–77	1977–78
Ardvar	17	88	97	100
Nedd	24	96	91	
Thurnaig	15	87		
Torridon	26			
L. Mhuirich	14	94		

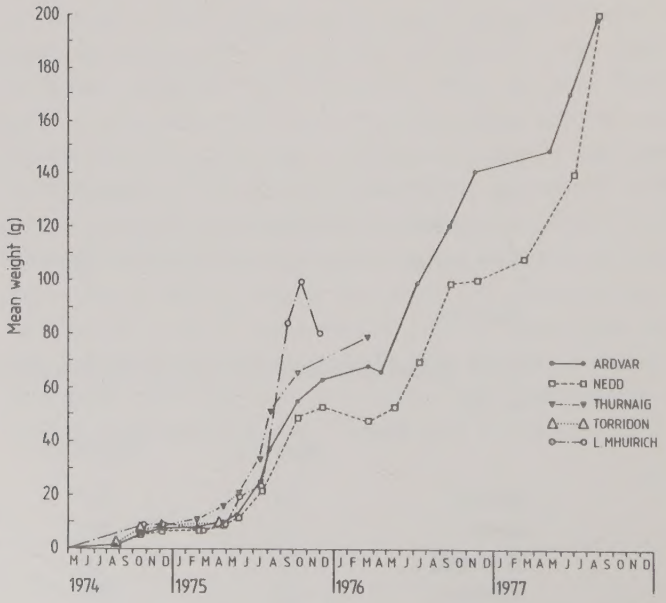

Figure 6. Mean weight of *Crassostrea gigas* (1974 seed).

Comparison of Raft and Shore Cultivation

Environmental Conditions

The area selected for experiments on shore cultivation was at the south east end of Loch Ardvar, where the lower shore consists of muddy sand containing a few scattered specimens of native oysters. Measurements of temperature and salinity at a range of depths were continued up to 1980, the results at 2m for 1976–1980 are shown in Figure 7. The temperature range over this period was 5.0°C–14.2°C, and the salinity never dropped below 30.0‰ despite the normal fluctuations in the ½–1m surface layer. The surface layer of low salinity extends over the whole loch during periods of heavy rainfall and contributes to the wide range of salinities endured by the shore oysters as it washes over them during the rise and fall of the tide.

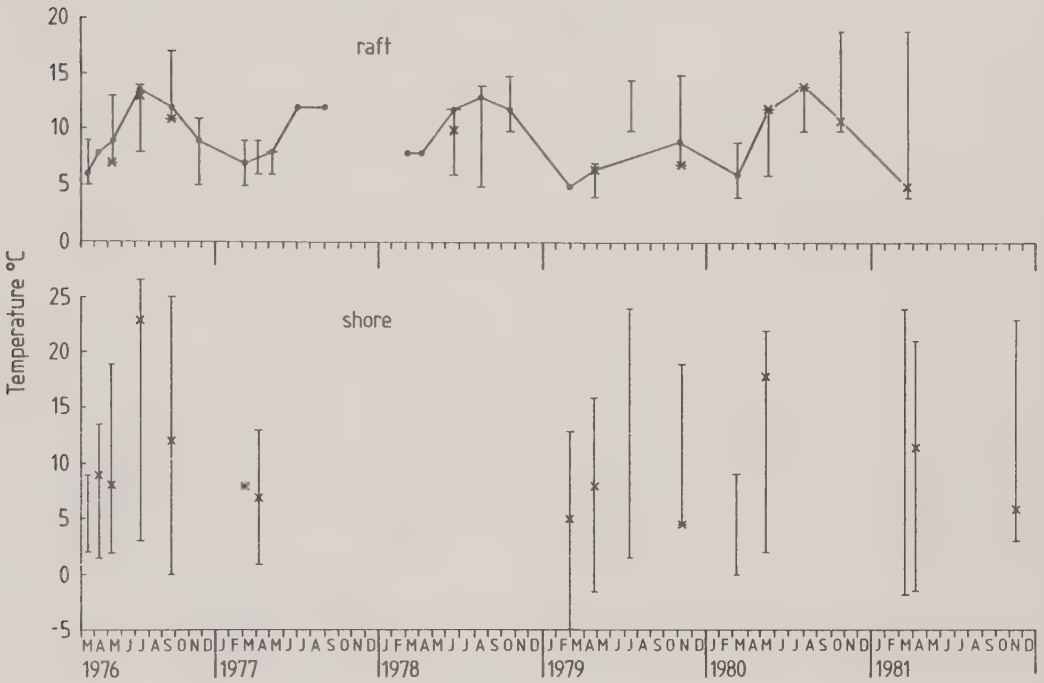
raft
shore
Temperature °C
20
15
10
5
0
25
20
15
10
5
0
-5
M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1976
1977
1978
1979
1980
1981

Figure 7. Temperature - Ardvar raft and shore. (. = water samples I = range and X = ambient temperature measured by max. and min. thermometer).

In 1976 a maximum/minimum thermometer was installed amongst oysters in a tray suspended fromthe raft at a depth of 2m and a similar thermometer was placed amongst the oysters in a tray at the top of a 4 tray stack in the mid-shore position. The readings from these thermometers are shown in Figure 7. The shore oysters suffered much wider extremes of temperature (–5.0°C to +26.5°C) than the raft (4.9°C to 19.0°C) since the former were subject to the greater extremes of the ambient air temperature exacerbated by wind chill on the one hand and the direct heating effect of the sun on the other.

Initial Trials

In May 1973 cages of oysters of both species were held clear of the bottom by stakes in order to reduce the amount of silt deposited amongst the animals. One set of cages was near low water springs (LWS) and the other at about low water of neap tides (LWN). A batch of 200 oysters of 10mm size were placed in each cage. In Table IV survival is compared with that on the raft, while growth is shown in Figures 8 and 9. Initial survival of *O. edulis* on the shore was poor compared with that on the raft, but there was not much difference between raft and shore in *C. gigas.* There was some variation in subsequent years, but overall the LWN position was the best for both species. Growth of *O. edulis* was clearly highest on the raft and lowest at LWN. In *C. gigas,* however, the growth pattern was different: initially the raft animals showed the best growth, but were overtaken later by those in the LWN position.

Table IV

Mean annual survival (%) — comparison of raft and shore (Ardvar) 1974 seed (10mm)

	1973–74	1974–75	1975–76	1976–77
O. edulis				
LWN	14	97	82	100
LWS	20	82	97	95
Raft	36	82	99	95
C. gigas				
LWN	24	83	100	
LWS	17	53	83	
Raft	16	80	81	

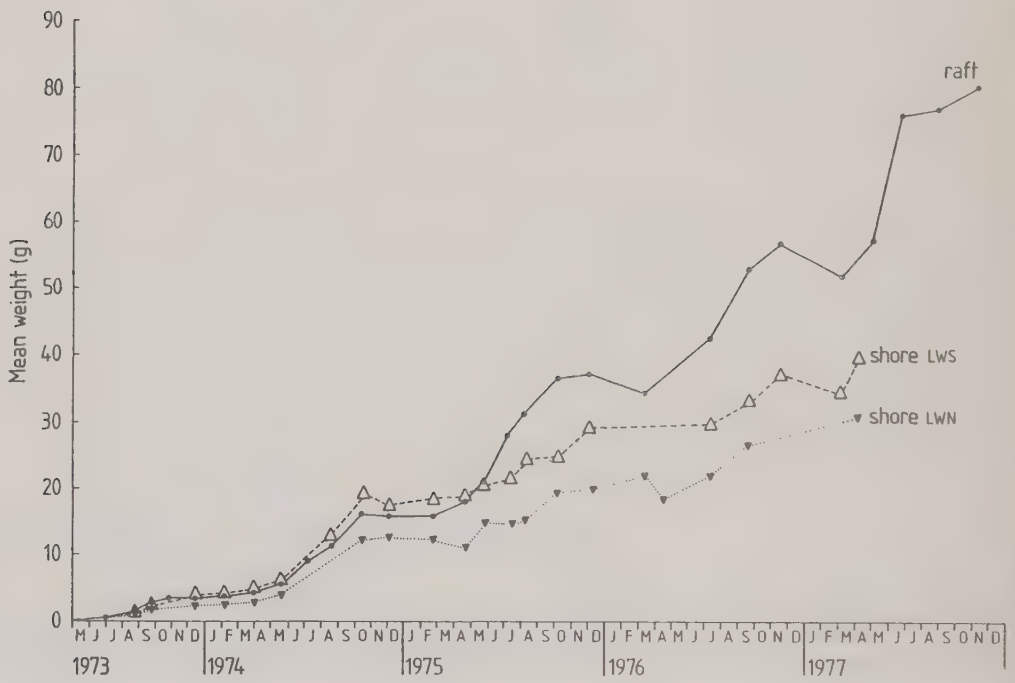
Mean weight (g)
raft
shore LWS
shore LWN
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1973
1974
1975
1976
1977

Figure 8. Mean weight of *Ostrea edulis* — Ardvar raft and shore.

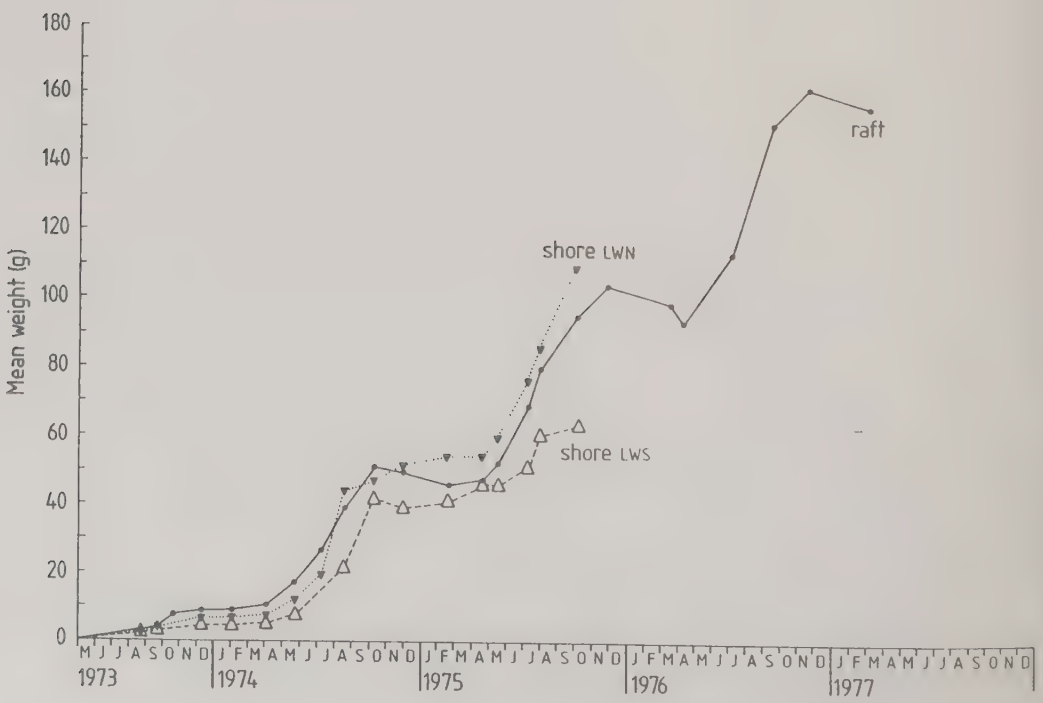
Mean weight (g)
raft
shore LWN
shore LWS
M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D J F M A M J J A S O N D
1973
1974
1975
1976
1977

Figure 9. Mean weight of *Crassostrea gigas* — Ardvar raft and shore.

A separate experiment set up in 1974 showed the effect of different degrees of protection on survival and growth. One set was laid directly on the shore, without protection, one set was covered with an inverted tray, and the third set was placed inside trays resting directly on the bottom. Table V shows that growth rates were similar, but the fully caged animals survived better.

A stack of four trays was set up in 1974 near LWS. A batch of 80 *C. gigas* of size 20mm was placed in each. The results are shown in Table VI. Growth rate clearly increased with increasing distance from the bottom, the effect of increasing exposure being more than offset by the relative freedom from silting in the upper trays.

Table V

Experiment to show effect of protection on oysters on shore (Ardvar)

	Mean Weights			% Annual Survival	
	23/05/74	25/04/75	13/05/76	1974–75	1975–76
	O. edulis				
Exposed	5.6	14.1	20.7	67	69
Covered	5.6	13.3	18.9	48	64
Caged	5.6	15.0	19.1	85	63
	C. gigas				
Exposed	13.0	41.6	83.1	58	87
Covered	13.0	52.6	83.2	77	95
Caged	13.0	48.9	88.3	92	100

Table VI

Growth of *C. gigas* in stack of four trays on shore at LWS (Ardvar)

	Mean weight (g)			Annual survival %	
Tray No	23/05/74	25/04/75	14/04/76	1974–75	1975–76
4 (Top)	2.3	19.5	58.5	69	95
3	2.4	18.5	50.0	77	97
2	2.3	16.3	51.6	72	86
1 (Bottom)	2.4	15.1	40.7	76	95

Growth under Different Conditions

Following the promising results of the first shore trials, an experiment was set up in April 1975 to study the growth and mortality of *C. gigas* under a variety of conditions. A number of cages were set up in various positions on the shore and in tanks at the Marine Laboratory field station in Loch Ewe. Each cage contained 50 animals of size about 50mm and mean weight 12.6g. Small mesh cages within each unit contained medium (10mm) and small (3mm) spat.

There was considerable fouling of the fine mesh and the small spat grew very slowly. The 10mm spat reached a mean weight of 5.5g on the raft by March 1976, but growth on the shore was very poor, reaching only 1.2g in the best cage (near LWS). The results for the larger (50mm) stock are shown in Table VII. Survival was good and the best growth on the shore (Cage No 6) was similar to that on the raft. This agrees well with earlier results, as this cage was near low water but raised off the bottom by Cage No. 7. Even the highest shore cage (No 2) gave better results than the tanks. The poorest growth was recorded in the standard tank (Cage 11), which had a limited supply of sea water from the header tank (containing Cage 18) which was fed direct from the sea.

Table VII

Growth of 50mm *C. gigas* under different conditions in various places. (Initial size 50mm, mean weight 12.6g on 25/04/75)

Cage Number	Position	Final mean weight (g)	Date	% survival
1	Ardvar Raft	59.0	14/04/76	96
	Ardvar Shore:			
2	MTL	35.1	—	98
3	LWN	45.7	—	98
4	" further NE	51.7	—	92
5	" further SW	44.4	—	100
	LWS:			
6	Upper tray	58.3	—	94
7	Lower tray	45.2	—	92
8	Below LW	48.3	—	96
9	Nedd LWS	43.6	17/03/76	94
	Ewe:			
10	Header Tank	24.8	19/05/76	100
11	Standard Tank	20.4	—	98

Effect of Tidal Height and Distance Above Bottom

To clarify the relationship between growth, tidal height and distance from the bottom an experiment was started in April 1976. Three stacks were erected to cover the heights from low water to mean tide level (Fig. 10). The "low stack" of 8 trays sited at extreme LW of spring tides, was covered at about LWN. The "high stack" of 12 trays at LWN was covered at MTL. A third, the "mid stack", contained 4 trays covered at about LWN and its purpose was to enable comparison of different distances from the bottom at the same height in relation to the tide. Fifty *C. gigas* of mean weight 10g were placed in each cage on 14 April 1976.

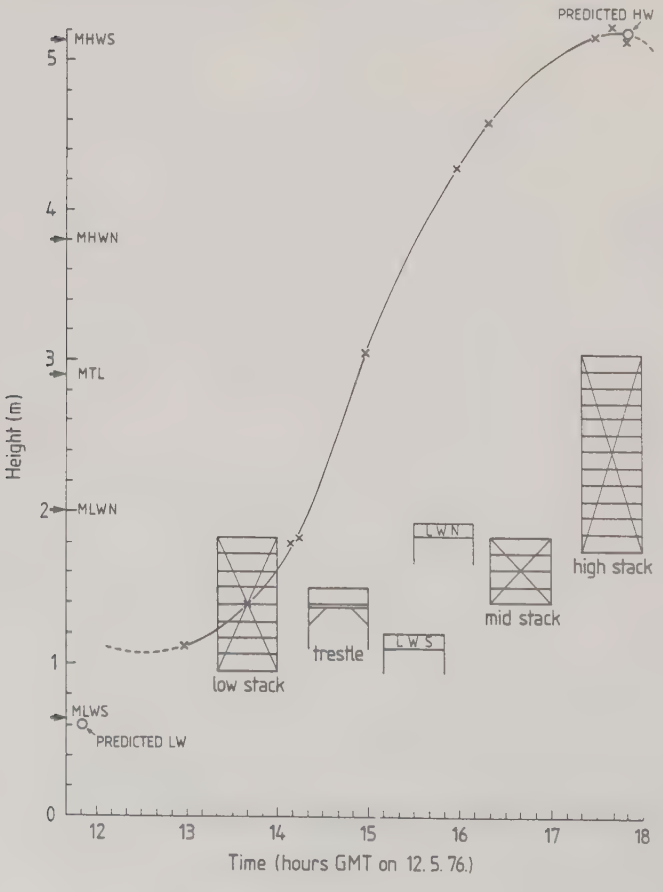

Figure 10. Shore structures at Ardvar in relation to tidal height.

The actual tidal level was recorded during a period of spring tides and calm weather, and linked to the predictions for Ullapool in the manner shown in Figure 10. Low water was almost 0.5m above the prediction. This fits well with other observations – there is a considerable difference between low water level inside and outside the loch, caused by the retarding effect of the sill. This effect is significant only near the time of low water when much of the sill dries completely.

Table VIII shows the results after one and two years. There is a certain amount of chance variation between trays but a general pattern emerges. There is an overall decrease in growth as the height in relation to the tide increases. Superimposed on this is an increase in growth as the height above the bottom increases. Growth and survival in the bottom cage of a stack are always poorer than in trays higher up the stack. The best results, better than a similar tray on the raft, were obtained in the 5th tray (counting upwards) in the low stack.

Table VIII

Growth of *C. gigas* in stacks of trays on the shore at Ardvar

	08/03/77						18/03/78					
	Low Stack		Mid Stack		High Stack		Low Stack		Mid Stack		High Stack	
	No	Wt(g)	No	Wt(g)	No	Wt(g)	No	Wt(g)	No	Wt(g)	No	Wt(g)
MTL					50	18.7					40	39.4
					39	23.7					28	48.2
					41	20.7					41	42.7
					41	23.2					37	43.9
					44	23.3					40	45.1
					46	20.1					42	38.7
					44	23.9					36	50.0
					42	24.2					38	46.0
					40	22.2					35	40.7
					39	23.7					36	40.3
LWN					38	27.6					30	50.8
	37	39.9	44	36.4	33	26.5	34	90.4	43	69.8	20	47.5
	43	39.5	40	35.6			42	82.1	34	75.7		
	44	42.0	36	37.5			38	92.8	30	68.3		
	41	47.0	35	36.7			37	98.6	34	58.8		
	41	40.2					32	94.5				
	35	40.0					28	74.1				
LWS	38	47.7					32	82.0				
	35	34.3					24	64.6				
Raft	40	45.6					36	88.2				

The initial (14/04/76) number and mean weight were 50 at 10g in each tray.

Transfer From Raft to Shore

Previous results had shown good early growth on the raft with growth on the shore catching up later. It was therefore decided to test the effect of transferring stock from the raft to the shore. The shore trays were supported on a trestle at the same height as the fifth tray up the "low" stack (Fig. 10). Four trays each containing 250 *C. gigas* spat of mean weight 0.2g were placed on the trestle on 7 April 1978 and four similar units were hung from the raft. On 15 October 1978 two trays were transferred from raft to shore. The results are shown in Table IX. Initial survival was best on the raft. After two growing seasons, growth on the shore had almost caught up with that on the raft. The group which were transferred from raft to shore showed the poorest growth. Taking both numbers and mean weight into account, the total yield of oysters was considerably higher on the raft, but the yield from the original shore trays was better than that from those transferred from raft to shore.

Table IX

Growth of *C. gigas* — raft, shore and transferred from raft to shore (Ardvar)

	Mean weight (g)			No		
	07/04/78	26/04/79	06/11/79	07/04/78	26/04/79	06/11/79
Raft	0.2	4.9	26.0	250	208	196
	0.2	5.5	26.5	250	152	152
Raft, to shore	0.2	2.9	17.4	250	179	152
on 15/10/78	0.2	3.2	15.8	250	180	155
Shore	0.2	3.3	22.6	250	150	136
	0.2	3.2	23.8	250	126	122
	0.2	3.4	24.4	250	144	134
	0.2	3.5	25.0	250	107	90
Means						
Raft		5.2	26.2		180	174
Raft to shore		3.1	16.6		179	153
Shore		3.3	24.7		132	120
Yield (total weight) per tray (g)						
Raft		936	4559			
Raft to shore		555	2540			
Shore		436	2964			

Predators and Competitors; Fouling

The two most frequently encountered oyster predators were *Carcinus maenas* L. on the shore and *Asterias rubens* L. on the raft. The effect of *Carcinus* is greater on oyster spat since only small crabs are able to pass through the mesh of standard trays and the size of *Carcinus* related directly to prey size. There is, however, the possibility that larger crabs are able to attack oysters through the mesh, although this was not observed. Aquarium experiments showed that larger specimens of *Asterias* (radius over 120mm) were capable of killing oysters through the mesh of a standard tray. During the maintenance of field experiments *Asterias* with radii up to 50mm were discovered inside trays in which high mortalities had occurred. Measurements of mortality often resulted in a discrepancy between the number of dead shells found and the number expected from the decrease in number of live oysters. This suggests that some other predator which does not leave an intact empty shell is capable of entering the tray, ingesting the oyster and then escaping. A possible candidate, occasionally found in the trays, is *Pholis gunnellus* L. which is known to prey on lamellibranchs (Qasim, 1957).

The principal competitors of cultivated oysters were found to be the fouling organisms mussels, barnacles, the tube worm *Pomatoceros triqueter* (L.) and the ascidians *Ascidiella aspersa* (O. F. Müller) and *Ciona intestinalis* (L.), all of which compete directly with oysters for food and space. Mussels, by the attachments of byssal threads, also restrict the feeding of oysters by preventing them from opening fully.

By far the most important effect of fouling organisms is that of blocking the mesh of the tray and thus impeding water exchange. Between visits the trays acquired a growth of filamentous brown algae, fucoids, *Laminaria* spp. and ascidians which was heavy during the spring and summer and especially bad in Linne Mhuirich. Although the method of killing ascidians by exposure to air described by Mason and Drinkwater (1981) can be applied to oyster trays, it does not appreciably affect the algal growth, which must be scrubbed off regularly. Shore trays had very little algal growth and always

had periwinkles, *Littorina littorea* (L.) on them. An experiment to test the effect on oyster growth of including *Littorina* in the trays suspended from the raft was, therefore, carried out at Ardvar. Varying numbers of *Littorina* were placed in both new clean trays and trays with one month's algal growth and these were compared with a control tray which contained no *Littorina* but which was scrubbed at intervals in the usual manner. The trays all started with units of twenty 40g oysters which were allowed to grow for 7 months. The results are shown in Table X and suggest that the effect of *Littorina* browsing on the algae leads to an increase in growth rate. The best growth was in the tray which started clean and contained periwinkles, while the worst was in the tray which started weedy and had no periwinkles.

Table X

Effect of periwinkles (*Littorina littorea*) on fouling of trays (Ardvar Raft)

	No of winkles	No of oysters	Mean Wt (g)	No of oysters	Mean Wt (g)	Rank order of growth
Treatment	14/04/76			21/11/76		
Clean regularly	0	20	40.0	19	98.7	3
Clean Start	0	"	"	19	97.4	4
	15	"	"	17	111.8	1
Weedy start	0	"	"	17	82.4	7
	5	"	"	20	93.3	6
	15	"	"	13	96.2	5
	45	"	"	16	100.0	2

Other Factors Affecting Mortality and Growth

Initial Size

Trials with 3mm seed of *C. gigas* were unsuccessful. The infrequent visits did not allow sufficient cleaning of the fine mesh cages and growth and survival were poor. Seed of around 10mm grew much better, but survival was disappointing. This was the size used in the early experiments. Once beyond about 15mm survival was much better, and these, or larger stock, were used in the later experiments.

Density

It was apparent from the earliest experiments that growth was density dependent. For example, in a tray containing eight surviving animals *C. gigas* had grown to 22.5g mean weight, whereas in a similar cage with 57 survivors the mean weight was only 8.4g. The great variability of survival made it difficult to arrange experiments to study density effects in detail. Table XI shows the results of two small experiments; in both *O. edulis* and *C. gigas* increasing initial density was accompanied by reduced survival and growth.

Table XI

Effect of density on growth and survival of oysters (in trays of area 0.25m^2)

No	Mean Wt (g)	No	Mean Wt (g)	Survival %
O. edulis (L. Mhuirich raft)				
29/05/74		30/04/75		
95	10.0	79	30.1	83.0
191	10.0	149	26.3	78.0
C. gigas (Ardvar raft)				
22/05/75		16/03/76		
50	0.2	11	6.8	22.0
200	0.2	45	5.5	22.5
500	0.2	92	3.4	18.4

In practice very low and very high densities are both undesirable, and as a rule of thumb an attempt was made to keep numbers per tray just below the level at which the animals would be touching when spread out evenly.

Depth

Results from trays at ½m depth at L. Nedd were compared with those from the standard depth of 2m (Table XII). *O. edulis* showed better growth at the shallower depth. The same was true for *C. gigas*, but survival, though variable, was better at 2m. After the second growing season the difference in mean weights was less.

Table XII

Effect of depth on growth of oysters (Nedd raft)

	Depth	No	Mean Wt (g)	No	Mean Wt (g)	No	Mean Wt (g)
		04/05/73		04/04/74			
O. edulis	½m	200	0.1	47	4.9		
		200		56	4.3		
	2m	200		54	3.1		
		200		54	3.4		
		04/05/73		04/04/74			
C. gigas	½m	200	0.1	27	11.2		
		200		18	9.2		
	2m	200		41	12.9		
		200		18	6.7		
		23/05/74		25/04/75		14/04/76	
	½m	200	0.2	40	15.0	39	64.1
	2m	200	0.2	49	8.9	47	52.7

Shell abrasion

The considerable loss in weight in winter in Linne Mhuirich has already been mentioned. It was accompanied by erosion of the shell of the oysters, leading to the death of many of them. In some cases the lower shells were reduced to a ring with a large hole in the centre. This was attributed to movements causing the shells to be rubbed against the bottom of the trays. It was thought that flotation was excessive, so that the raft bounced about in bad weather.

During the winter of 1975-76 an experiment was carried out in Loch Ardvar in which four trays each containing 50 *C. gigas* of mean weight 45.0g were compared, all being placed at the usual depth of 2m. One was suspended from a large cluster of floats, the second was given a much smaller amount of buoyancy, the third was hung from the raft in the normal way and the fourth was placed on the seabed in the same area. The oysters in the tray with excessive flotation suffered heavy mortality and loss of mean weight. (Table XIII).

Table XIII

Effect of excessive flotation (Ardvar)

Tray No		03/12/75 Mean Wt No	(g)	14/04/76 Mean Wt No	(g)
1	Max. flotation	50	45.0	21	28.6
2	Min. flotation	50	45.0	50	47.3
3	Raft	50	45.0	49	47.3
4	Bottom	50	45.0	49	47.3

Oysters placed in trays on the shore were subject to direct wave action at certain states of the tide. They tended to be concentrated in one corner of the tray but showed little abrasion.

Condition and Meat Yield

A number of methods of determining meat yield were tried. Figure 11 shows the results of careful measurements of one batch of *C. gigas*, the 1973 seed at Ardvar measured in October 1975. The dry shell accounted for more than half the total weight, (54%). The meat made up only 14% in this particular sample, and only 4.5% when dried. The interstitial water in the shell cavity amounted to 18%. The total water content was 41.5%. There is a considerable amount of salt in all this water so that in a poor oyster the total salt

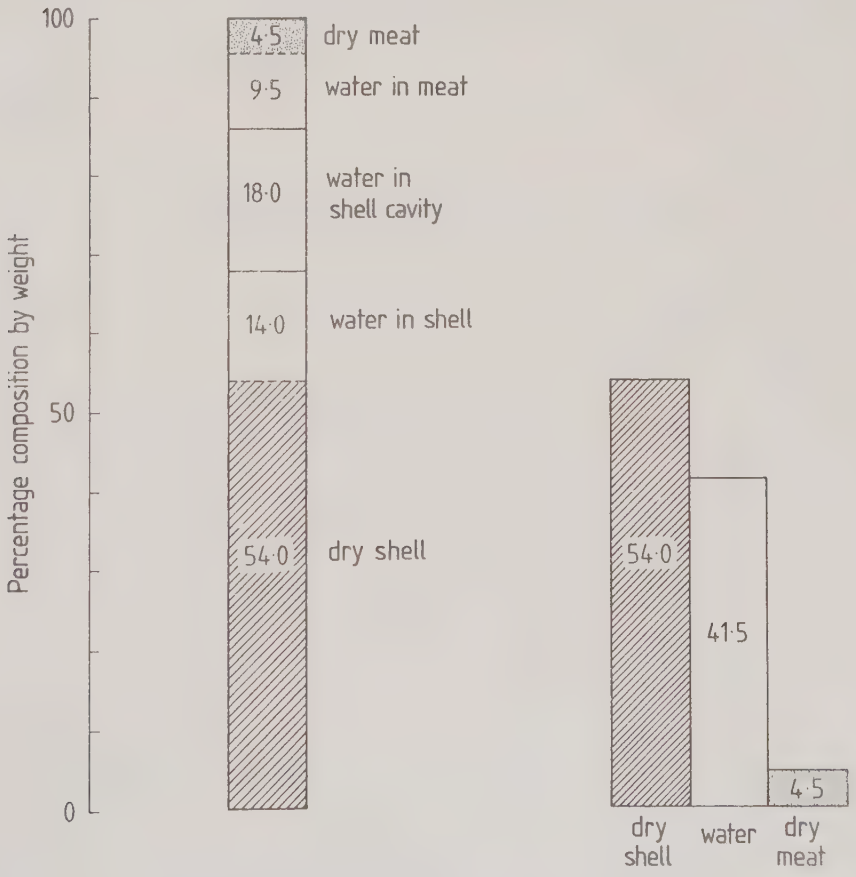

Figure 11. Composition by weight of *Crassostrea gigas* — Ardvar.

content could be higher than the weight of dry meat. Experimental difficulties were caused by the fact that liquid oozed from the meat for a considerable time after it was cut from the shell, and water was lost by evaporation during handling. Further tests showed that boiling firmed up the meats but resulted in a large and variable weight loss. Freezing had less effect, but on thawing out the meats were very soft. Methods are discussed by Baird (1978) and Quayle (1980). None gives a complete measure of the condition of the meats, for which chemical analysis would be required.

The meat content may be expressed in a number of ways, as shown in Table XIV which also gives the values worked out for the same sample as Figure 11. It was decided to standardise on the following method: the oysters were weighed whole, while still full of water, the adductor muscle cut so that the shell opened, the water allowed to drain out for ten minutes and the shell and meat together weighed again. The meat was then removed from the shell and the shell weighed alone. The wet meat weight was obtained by difference. Shell and meat were dried to constant weight at 85°C and the dry weights obtained after cooling for a few minutes. If allowed to stand for longer there was considerable absorption of water from the atmosphere. The results are expressed as wet meat yield, a simple and direct measure, and as shell condition index (SCI), the value least open to experimental error.

Table XIV

Meat content of *C. gigas* oysters (as shown in Figure 11)

Wet meat yield	$\frac{\text{Wet meat}}{\text{Total}} \times 100$	14.0
Dry meat yield	$\frac{\text{Dry meat}}{\text{Total}} \times 1000$	45.0
Wet condition factor	$\frac{\text{Wet meat}}{\text{*Internal Volume}} \times 100$	30.0
Dry condition factor	$\frac{\text{Dry meat}}{\text{*Internal Volume}} \times 1000$	97.8

*Internal Volume is approximately Total weight - Shell weight, as specific gravity of meat is close to 1.

Shell condition index	$\frac{\text{Dry meat}}{\text{Dry shell}} \times 1000$	83.3

Table XV shows results from the different sites. The best meat yields were found in Linne Mhuirich and Ardvar in October. The apparently favourable result from Torridon in December 1974 was caused by extensive shell abrasion reducing the weight of the shell.

Table XV

Condition and meat yield of oysters

	Mean Total Wt (g)	Wet Meat %	SCI	Mean Total Wt (g)	Wet Meat %	SCI	Mean Total Wt (g)	Wet Meat %	SCI	Mean Total Wt (g)	Wet Meat %	SCI
O. edulis												
	October 1974			December 1974			September 1976			November 1976		
Ardvar	15.0	28	52				54.4	11	35			
Nedd	15.8	20	38				52.8	13	42			
Thurnaig	18.2	15	40									
Torridon				20.7	19	40						
L. Mhuirich	23.0	24	71							73.5	18	50
C. gigas												
	October 1974			December 1974			October 1975			December 1975		
Ardvar	52.4	24	83	44.6	27	55	75.6	24	84	50.0	16	38
Nedd	44.8	25	71				101.5	23	74			
Thurnaig	47.8	26	62				117.0	20	68			
Torridon				32.8	42	118				49.1	16	43
L. Mhuirich	59.6	30	82				98.4	23	84			

Seasonal variation was studied on both raft and shore at Ardvar during 1976-77 (Fig. 12). The percentage of wet meat was mostly between 17 and 22%, while the shell condition index ranged from 26 to 75. Values were generally high during the summer and autumn when higher temperatures and food levels had allowed a build up in condition. Over the winter values fell considerably. The low figures, for the raft only, in August 1977 suggest the possibility that spawning took place, at least in some animals, but this was not confirmed by microscopic examination. A few individuals were thin and watery at all times of the year. There was no evidence of development of unpleasant taste or odour associated with resorption of gonad products over the winter as had been suggested by a commercial grower. There was a general decline in fullness by the spring, however, accompanied by a rather bitter taste. This was perhaps caused by the normal taste of the mantle region, which is masked in fuller individuals by the creamy gonad tissue.

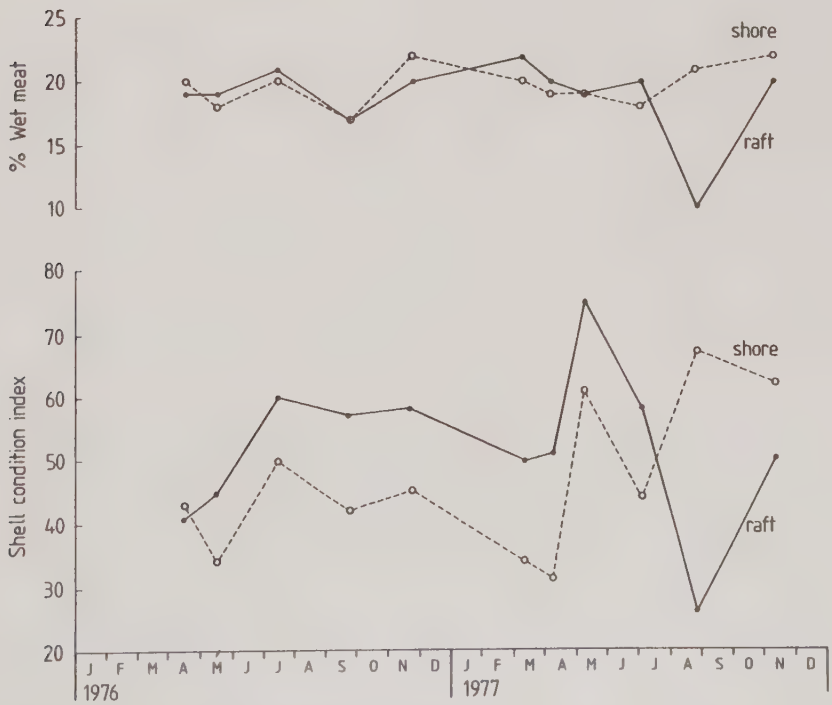

Figure 12. **Meat content and shell condition of *Crassostrea gigas* — Ardvar raft and shore.**

The variation during 1978 in shell condition index at different heights on the shore is shown in Table XVI. Samples were taken from the three stacks mentioned earlier (Fig. 10). The lowest trays generally gave better results, the best individual result being in August when the SCI reached 85.6. There was a decline in October. Note the particularly low figure for the bottom tray of the stack suggesting that condition varied in the same way as growth (See page 11). These results were confirmed by an experiment in 1980 in which four trays, each on top of an empty tray to cut down silting, were put at four different heights on the shore. The trays lower on the shore again generally showed the better results (Table XVI).

Table XVI

Shell condition index — *C. gigas* Ardvar Shore

Date		SCI Low Stack	Mid Stack	High Stack	Raft	
08/03/78		46.3	35.8	32.0		
07/04/78		54.7	41.5	36.9		
20/06/78		42.6	54.5	44.4		
21/08/78		85.6	58.1	44.7		
26/10/78	(	53.0		50.5		
	(	*40.7		42.1	52.4	* = bottom tray

	Tray No:	1	2	3	4 (highest)
30/07/80		48.8	56.9	45.6	45.2
23/10/80		59.6	56.9	52.9	43.9
09/03/81		40.8	28.8	31.5	30.8

Another aspect of the quality of the oysters concerns their shape. *C. gigas* is noted for large variation in the shape of individuals, though this is difficult to quantify. The most elongated and irregular shells were found in those grown directly on the shore and subject to the effects of silting.

Individual weights could not be measured in the field, and the mean weights obtained in the growth experiments gave no indication of the amount of variation amongst individuals. This was therefore studied in the meat yield samples which had been treated in the same way in the field. The variation is best expressed as the coefficient of variation (standard deviation expressed as a percentage of the mean) which in analyses of the individual weights ranged from 26 to 50%. The proportion of meat was less variable, giving coefficients of variation of under 20%. Applying these results to the previous results from growth experiments the likely yield of meat can be predicted. After three growing seasons 10mm seed of *C. gigas* had grown to 100g mean weight. If we assume a coefficient of variation of 40% then 83% of these animals would be over 60g and most would have meats in excess of 12g. If they had been sorted after two seasons' growth, when the mean weight was 60g, around half of them would have had meats in excess of 12g, and these would have been of marketable size.

Discussion

These experiments have confirmed that *Crassostrea gigas* can be grown to commercial size at a number of places on the west coast of Scotland in 2 to 3 years. *Ostrea edulis* grows more slowly and would take 4 to 5 years to reach a marketable size. Commercial operations are now (1985) in progress in several places, and small scale trials are being made at a large number of sites in Scotland, mostly on the west coast and in the Western and Northern Isles.

The results described in this paper should be examined in the light of three important points. The first is the extreme variability of *C. gigas.* In the main growth experiments at different sites and at different heights on the shore, a pattern emerges in spite of some random variation. Some caution should be exercised, however, in interpreting the results of the smaller experiments. The second point concerns the difficulty in standardising conditions in different places and at different times. This is linked directly to the third point — the interdependence of the various factors. A few examples may be cited. There is more fouling of cages in Linne Mhuirich than elsewhere because the fouling organisms (like the oysters) grow quickly. If the cages could be kept perfectly clean the growth rate of oysters would be even higher. Animals in trays in stacks are influenced by the amount of exposure (reducing growth in the higher trays) and the amount of silting (which reduces growth in the lowest trays of a stack). A very large array of stacks of trays would be required to show the separate effects of these factors.

In spite of these difficulties, however, certain conclusions can be drawn. There is a clear link between growth and summer temperature. Thus Linne Mhuirich had the highest summer temperatures and also the best survival and growth rates. It also had the lowest winter temperatures but this is not important since there is little food available at this time. Spencer and Gough (1978) reached similar conclusions in North Wales.

The results of experiments on the shore were very encouraging — probably owing in part to the absence of fouling organisms on the shore cages. It suggests that good growth and fattening could be obtained at far less expense than is involved in suspended cultivation. Predation by starfish is reduced by the regular exposure to air, but crabs would be a problem if regular checks were not made. The first thing would-be cultivators should look for in choosing a site is adequate shelter. Next they should seek a place which is not too deep and which has a restricted interchange with the open sea. Such a place will show relatively high summer temperatures and these will give a good indication of likely growth rates. If there is a suitable area of shore this should be used for the first experiments, and oysters of a fairly large initial size should be chosen. This will give a useful indication of growth rates within one season. If results are good, more detailed tests can follow, but the handling of very small spat should be regarded as a specialised operation needing more experience.

Summary

The feasibility of raft cultivation of oysters was investigated in a number of lochs on the west coast of Scotland. In Linne Mhuirich (Loch Sween), where summer temperatures were high, *Crassostrea gigas* grew to commercial size (75-100g) in 2 years. In Loch Thurnaig (Loch Ewe) and Lochs Nedd and Ardvar (Sutherland) growth was slower, but commercial size was reached in 3 years. Results were less good in Loch Torridon, where low salinities were recorded at times. *Ostrea edulis* grew much more slowly in all areas, taking twice as long to reach commercial size.

Cultivation of *C. gigas* in stacks of trays on the shore at Ardvar yielded promising results. In the best position – about 0.5m off the bottom near low water – growth rates were similar to those on the raft. Oysters transferred from raft to shore cages did not grow as well as those put out originally in shore cages.

Further experiments showed that fouling and high density reduced growth and survival.

Meat yields from *C. gigas* on both raft and shore were around 20% of total weight. The condition was best in the summer and declined during the winter.

Shore experiments using oysters of a fairly large initial size yielded the quickest results and are thus recommended for testing the suitability of sites.

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